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RELIABILITY DEMONSTRATION FOR AN EDDY CURRENT NDE TECHNIQUE USING A COMPUTATIONAL ELECTROMAGNETIC MODEL-ASSISTED APPROACH (POSTPRINT)

John C. Aldrin, Jeremy Knopp, Eric Lindgren, Charles Annis, Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy

Nondestructive Evaluation Branch
Metals, Ceramics & Nondestructive Evaluation Division

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MATERIALS AND MANUFACTURING DIRECTORATE
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John C. Aldrin (Computational Tools)
Jeremy Knopp and Eric Lindgren (AFRL/RXLP)
Charles Annis (Statistical Engineering)
Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy (Victor Technologies, LLC)

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Computational Tools
Gurnee, IL 60031

Nondestructive Evaluation Branch (AFRL/RXLP)
Metals, Ceramics & Nondestructive Evaluation Division
Materials and Manufacturing Directorate
Wright-Patterson Air Force Base, OH 45433-7750
Air Force Materiel Command, United States Air Force

Statistical Engineering
Palm Beach Gardens, FL 33418

Victor Technologies, LLC
Bloomington, IN 47401

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14. ABSTRACT
Reliability studies in terms of probability of detection (POD) evaluation are a critical component of nondestructive evaluation (NDE) inspection system validation. POD studies provide engineers with data on the reliability of detecting cracks across a distribution of sizes that can be used as an input to probabilistic risk assessment analysis. Traditional POD evaluation methodologies are entirely empirical. In most cases, the cost of manufacturing the number of samples required for a traditional POD study is prohibitive and may delay or prevent a new inspection procedure or new technology from being implemented. A new strategy for the design and execution of POD studies has been discussed using a model-assisted POD (MAPOD) approach. A demonstration study is presented for a class of aerospace structural inspection problems and considers the use of computational electromagnetic models and new statistical analysis methods in the POD evaluation. The volume integral method was successfully used to simulate eddy current measurements for varying crack length around fastener holes in a two-layer aluminum structure. Good agreement was achieved between experimental and full model assisted (FMA) approaches.

15. SUBJECT TERMS cracks, eddy current, probability of detection, reliability, volume integral method

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Reliability Demonstration for an Eddy Current NDE Technique Using a Computational Electromagnetic Model-Assisted Approach

John C. Aldrin[1], Jeremy Knopp[2], Eric Lindgren[2], Charles Annis[3], Harold A. Sabbagh[4], Elias H. Sabbagh[4], and R. Kim Murphy[4]

[1] Computational Tools, Gurnee, IL 60031, USA
aldrin@computationaltools.com,

[2] Air Force Research Laboratory (AFRL/MLLP), Wright-Patterson AFB, OH 45433, USA
Jeremy.Knopp@wpafb.af.mil, Eric.Lindgren@wpafb.af.mil

[3] Statistical Engineering, Palm Beach Gardens, FL 33418, USA
Charles.Annis@StatisticalEngineering.com

[4] Victor Technologies LLC, Bloomington, IN 47401, USA
has@sabbagh.com, ehs@sabbagh.com, kimmurphy1@aristotle.net,

Abstract: Reliability studies in terms of probability of detection (POD) evaluation are a critical component of nondestructive evaluation (NDE) inspection system validation. POD studies provide engineers with data on the reliability of detecting cracks across a distribution of sizes that can be used as an input to probabilistic risk assessment analysis. Traditional POD evaluation methodologies are entirely empirical. In most cases, the cost of manufacturing the number of samples required for a traditional POD study is prohibitive and may delay or prevent a new inspection procedure or new technology from being implemented. A new strategy for the design and execution of POD studies has been discussed using a model-assisted POD (MAPOD) approach. A demonstration study is presented for a class of aerospace structural inspection problems and considers the use of computational electromagnetic models and new statistical analysis methods in the POD evaluation. The volume integral method was successfully used to simulate eddy current measurements for varying crack length around fastener holes in a two-layer aluminum structure. Good agreement was achieved between experimental and full-model assisted (FMA) approaches.

Keywords: cracks, eddy current, probability of detection, reliability, volume integral method.

1. Introduction

New nondestructive inspection (NDI) techniques continue to be developed and applied to address new inspection requirements and/or improve existing techniques. To validate the performance of new inspection techniques, Probability of Detection (POD) studies can be performed. A POD study includes preparation of multiple samples that closely mimic the geometry of the structure to be inspected. These samples include a statistically significant number of inspection opportunities containing a distribution of flaw sizes and locations anticipated in the structure. The preparation of POD samples and the process to acquire data from these samples is often very time consuming and expensive. This is especially true for samples that include fatigue cracks, which should be grown using load profiles typically seen by the structure of interest to accurately represent

fatigue cracks that could be present. The financial and time burden can become significant hurdles in the development and execution of POD studies when validating new inspection techniques.

A new strategy for the design and execution of POD studies has been proposed [1] and recently advanced as a part of the Model-Assisted POD (MAPOD) Working Group [2]. One MAPOD approach includes the use of transfer functions to enable Electric Discharge Machined (EDM) notches to be used as substitutes for grown fatigue cracks while minimizing uncertainty in the sensitivity of the detection process. However, this requires preparation of a large number of test samples. An alternative MAPOD approach uses advanced computer simulations to model the inspection process and determines the POD for the inspection technique through a combination of experimental and simulated data. It is important to note that these models must address parameters in the structure that can affect the interaction of the inspection method with the structure, such as tapers, multiple layers, air gaps, fastener types, fastener fit, and other variables introduced by design, manufacture, and/or previous repairs. Using computer and empirical models to address these variables that cannot be easily recreated in experimental samples is a significant opportunity.

2. Reliability Demonstration Using Model-Assisted POD Evaluation

A demonstration is presented for a full model-assisted (FMA) POD methodology incorporating computer simulation for the inspection of cracks around fastener sites in a two layer aircraft wing-type structure inspection performed with an eddy current technique [3]. The demonstration follows a proposed FMA protocol [2] including the following steps: 1) identify the scope of the POD study, 2) identify factors that control signal and noise, 3) evaluate quality of physics-based models, 4) acquire, develop, and validate simulation tools, 5) acquire input parameters and parameter distributions, 6) conduct flaw signal distribution simulations and noise signal distribution simulations, 7) acquire remaining information on factors empirically, 8) acquire marginal information on independent factors, 9) acquire covariance information on dependent factors, 10) combine 6, 8, and 9 into full signal and noise distributions, and lastly 11) compute POD curve and probability of false call rate (POFC).

To validate the proposed model-assisted POD methodology, a set of experimental data for hidden cracks around fasteners in multilayer structures was analyzed [4]. The first and second layer thickness values were 0.156" and 0.100" respectively and made of 7075-T651 aluminum. Real fatigue cracks were manufactured varying from 0.020"-0.169". Raster scan data was acquired from these samples using a conventional eddy current probe at 600 Hz. New feature extraction and automated signal classification algorithms were developed and applied to the experimental data set demonstrating the ability to detect small cracks around fasteners while maintaining a low false call rate [4].

Simulated studies were also performed incorporating the experimental problem geometry of an eddy current inspection of a two layer structure with a fastener site and a crack [4]. Parametric studies were performed investigating varying crack size and type, considering both through and corner crack geometries (Figure 1). VIC-3D®, a commercial software package based on the volume integral method [5], was used to perform the simulations and found to address a great majority of the model variables. The simulated and experimental data for a given probe and inspection geometry were equated using a calibration procedure developed in prior work [6]. Figure 2 presents the calibration results demonstrating good agreement between the model and simulated data for the no-crack fastener site. Figure 3 presents a comparison of the simulated and model data for varying crack length and crack type (corner, through). In general, there is good agreement between the two data sets with some error for select experimental data points. Figure 4(a) presents the experimental data including the response for unflawed specimens. The distribution of the unflawed data shown in Figure 4(b) was used to represent the noise distribution of the experimental eddy current measurement system.

A Monte Carlo simulation was performed using the noise distribution for the unflawed fastener sites, the corner crack model, and the through crack model, to populate the full-model assisted data sets for POD evaluation. Additional details on the FMA methodology applied to this problem can be found in [3]. Figure 5 presents a comparison of the POD results for the experimental and full-model assisted approaches. A good

match was achieved between experimental and full-model assisted (FMA) approaches where the FMA POD curve was found to be within the confidence bounds (95%) of the empirical POD curve. This good result was achieved while limiting the experimental measurement data included in the noise distribution evaluation for the model-assisted evaluation from only unflawed specimens.

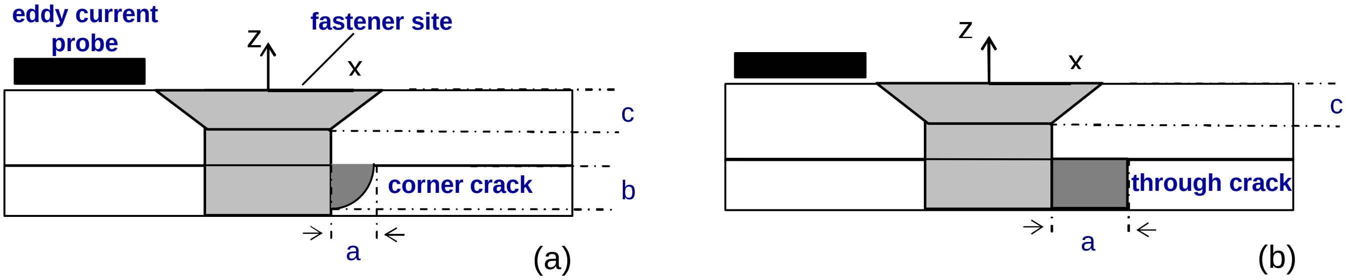

Figure 1. Diagram of fastener site model with (a) a corner crack and (b) a through crack.

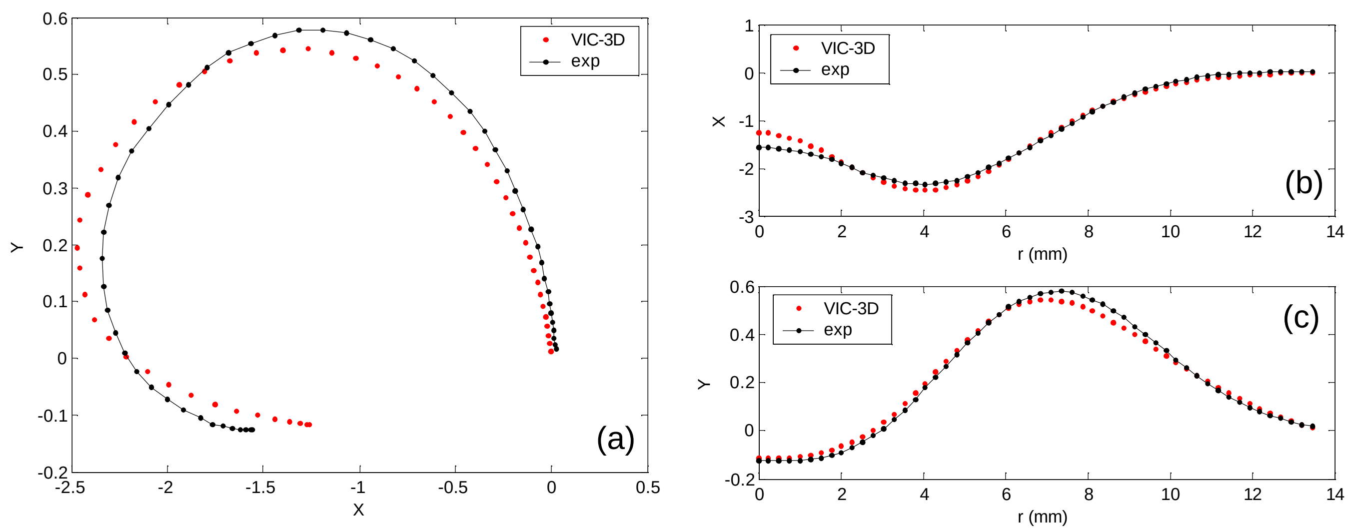

Figure 2. Calibration fit of model with respect to experimental data for titanium fastener site (X, Y in Volts).

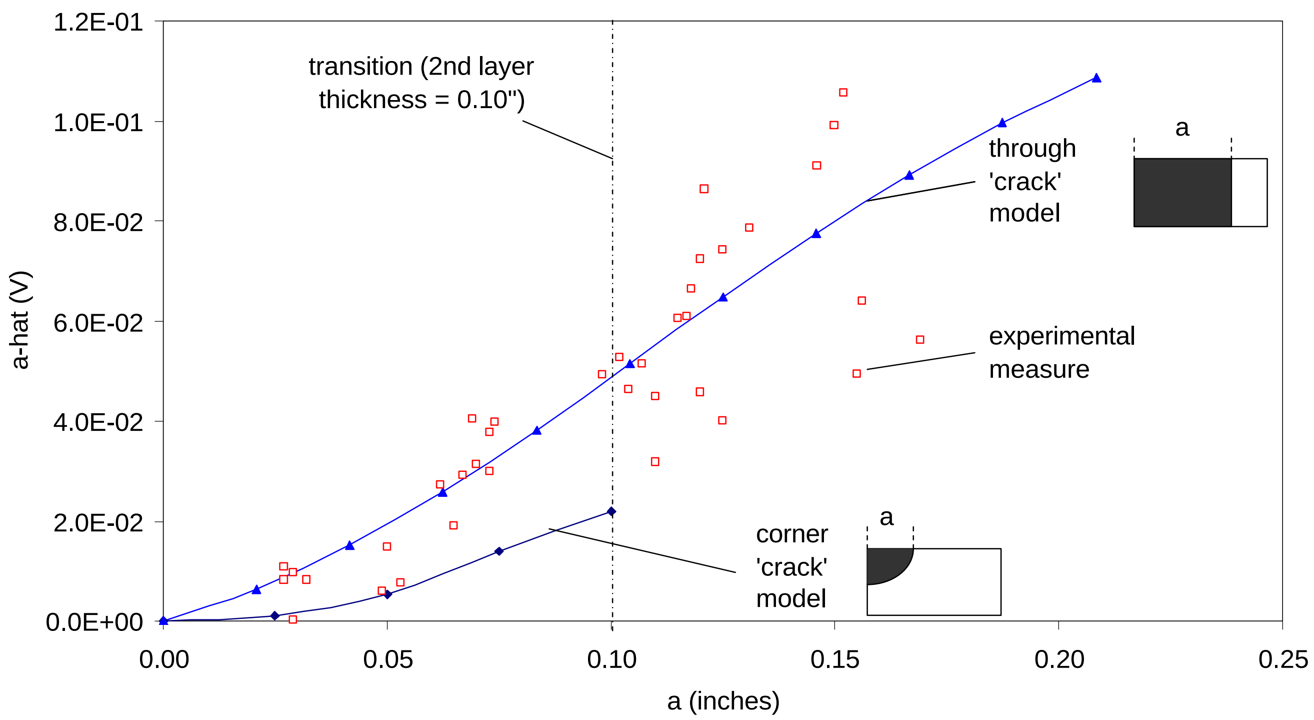

Figure 3. Comparison of experimental and simulated data for varying crack length and type.

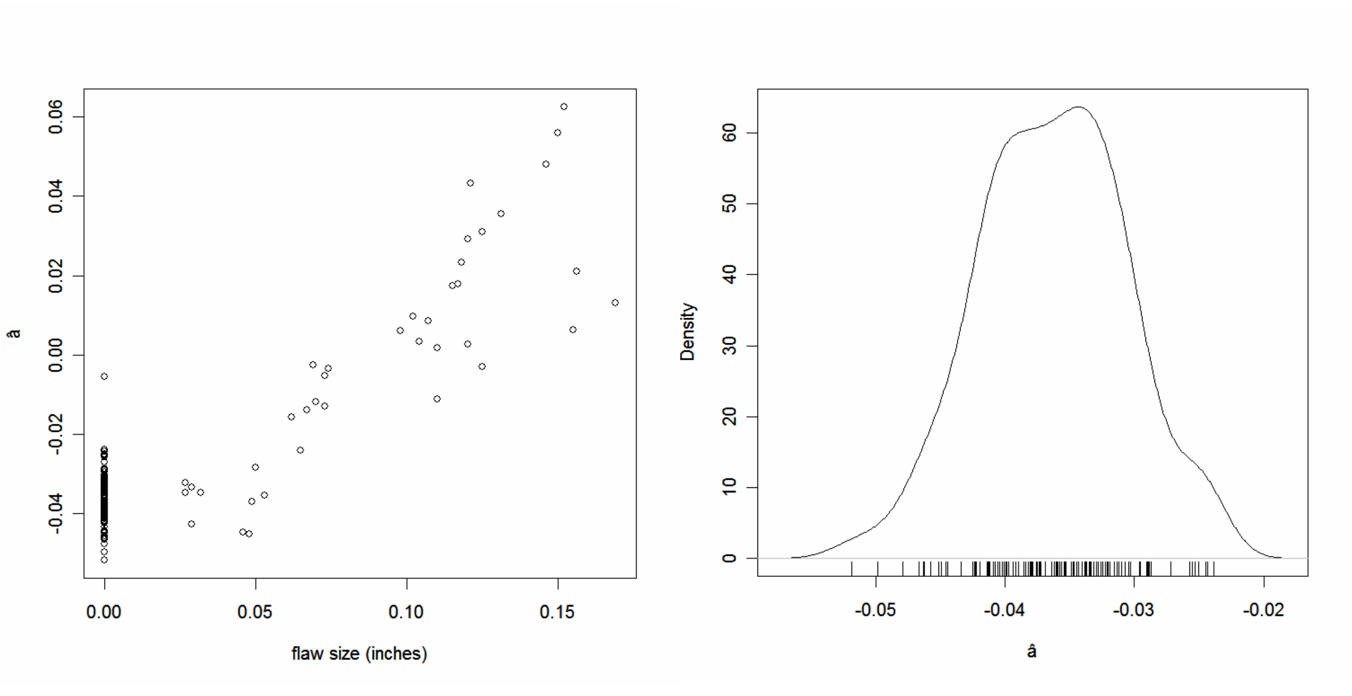

Figure 4. (a) Experimental data including unflawed responses with the corresponding (b) probability density function for unflawed data.

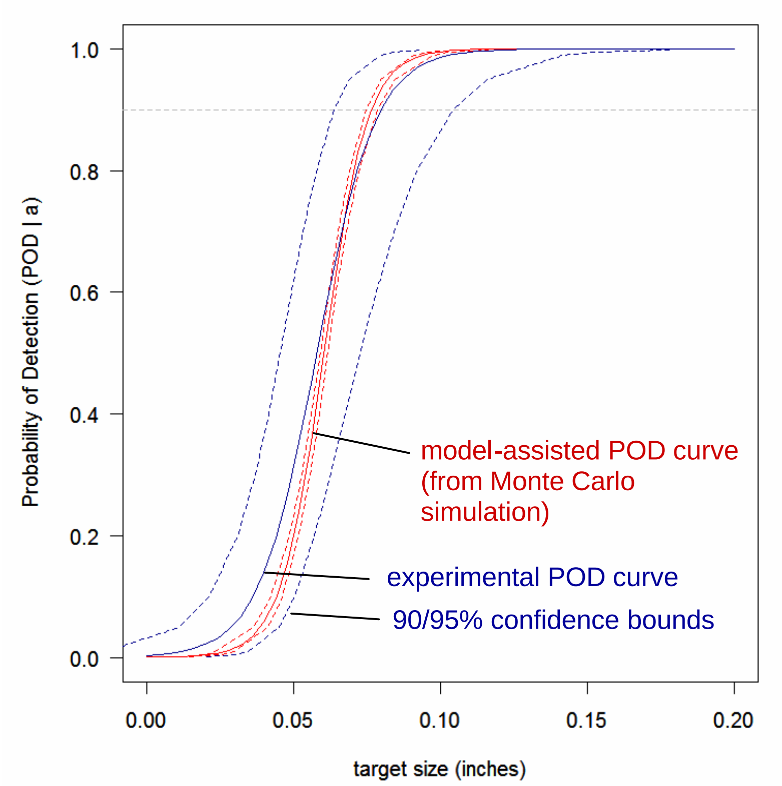

Figure 5. POD evaluation results for experimental and full model-assisted POD studies.

3. Results and Conclusions

The feasibility of using a model-assisted POD evaluation approach was demonstrated for eddy current NDE techniques applied to aerospace structures. A good match was achieved between experimental and full-model assisted (FMA) approaches where the FMA POD curve was found to be within the confidence bounds (95%) of the empirical POD curve. An advantage of the FMA approach was demonstrated by only requiring empirical data from unflawed samples, indicating the potential for cost savings associated with minimizing the manufacture of samples with real flaws. This model-assisted approach can also likely be extended to address problems of varying fastener diameter, thickness of multiple layers, crack location, scan plan and probe designs. However, significant challenges remain in developing MAPOD, including improvements to the existing computer modeling software, incorporation of multiple structural variables to accurately determine the damage in the structure, optimization of the methodology to combine both test samples and computer simulations, and determination of the uncertainty in the inspection process when both experimental and computer simulation data is used.

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